2008 International Conference on Condition Monitoring and Diagnosis, Beijing, China, April 21-24, 2008

The Application of On-Line PDM on in-service MV Cable Terminations

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***Abstract*-- The majority of cable failures on distribution system is caused by the defects in cable terminations and cable joints. Failure mechanisms reported in cable accessories are predominantly involve partial discharge deterioration caused by voids, contaminants and workmanship problems. Therefore, partial discharge measurement (PDM) is an effective diagnostic preventing cable system failure. However, conventional PDM needs outage and time consumption, and it is not practice for routine test in field. Then on-line PDM is an alternative diagnostic. This paper utilizes electromagnetic field coupling mode for on-line PDM on MV cable terminations. Hence, the background noise, usually less than 40 Mhz in authors' experience, could be eliminated by means of using ultra-high frequency as mid-band frequency. A performance check of on-line PDM shows good agreement with conventional PDM. Among more then 5,000 cable terminations diagnosed by on-line PDM, there are about 200 cable terminations having PD signals. Disqualified cable terminations are dissected, and the defects and PD patterns have some relationships between them. Therefore, on-line PDM is practicable for cable termination diagnostics on-site.**

***Index Terms*-- Partial Discharge, Cable insulation, Diagnostic**

I. BACKGROUND

Cable and its accessory usually pass sever routine test in factory, and the reliability is also high. However, cable system still can't prevent failure before its designed lifetime ends. In authors' experience, the amount of cable terminations is quite large as the amount of cable failure is few. The statistic data in literature [1] shows the same conclusion. Because cable termination needs hand-made installation in the field, the workmanship becomes a key issue. Besides workmanship, the cable termination is usually not properly tested after assembled, and this is also a concern. Oppositely, there is no need to change cable structure, and cable is careful treated. Therefore, the cable termination is a weak point in cable system, rather than cable.

The ageing mechanism of cable insulation can be roughly divided into two ways. One is the entirety ageing, such degradation can be detected by conventional diagnostic test, like DC high voltage withstand test, etc. Another one is discrete condition caused by defects complied with installation and manufacture. The defects are not easily detected by conventional diagnostic test due to the insufficient loss relative to overall material. Unfortunately, the failure mechanism of cable insulation is usually classified as the latter. Therefore, the failure of in-service cable system remains through the routine test in field is done.

There are many researches deal with these problems, and the alternative diagnostic tests are developed such as VLF, OWT, which can effectively detect these defects. However, these developed methods are used as off-line test, and are unfeasible for in-service due to time consumption. On-line PDM is another way to solve these problems. Its advantage is that no outage is needed, and its disadvantage is that only limited small part of cable system can be tested due to the large capacitance of cable system.

Based on authors' experience, the majority of cable failures on distribution systems are caused by the defects in cable terminations and cable joints. Failure mechanisms reported in cable accessories are predominantly involve partial discharge deterioration caused by voids, contaminants and workmanship problems. Hence, the on-line partial discharge measurement is practicable without dealing with long cable lines. Besides, on-line partial discharge measurement also has the advantage that no system contingency problems will arise and the influences of false damage signals due to inappropriate switching are solved. In order to get high signal to noise ratio, authors use ultra-high-frequency bandwidth sensor to do measurement.

A 22.8 kV power plant is taken as an example, and this paper utilizes electromagnetic field coupling mode for on-line PD measurement on all MV cable terminations in the power plant. The disturbing influence of external noises in the environment could be eliminated by means of choice ultra-high frequency as measuring frequency. Among more then 5,000 cables terminations diagnosed by on-line partial discharge measurement, there are about 120 cable terminations having PD signals without surface erosion, and 20 cable terminations having PD signals and powder/carbonization on their surface.

Disqualified cable terminations are replaced and are dissected. Dissection and PD patterns show good agreement, and have some relationships between them. Therefore, on-line PDM is practicable diagnostic of cable termination.

Table 1 Summary of Tested Cables

Type	PD Signal	Appearance	Amount
A	Yes	Normal	120
B	Yes	Powder/ Carbonization	20
C	No	Normal	4860

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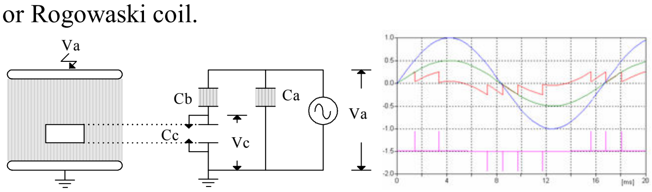
II. TEST METHODLOGY

According to IEC 60270, coupling capacitor is needed to do partial discharge measurement. However, there is a big problem to install coupling capacitor on a energized cable, and the additional cost due to de-energize is also needed to be considered. Hence, on-line partial discharge measurement on cable system is developed.

The defect and insulation material forms a voltage divider, and they get different intensity of electric fields. Usually, the breakdown voltage of defect is lower than the breakdown voltage of insulation material. While the intensity of electric field in the defect exceeds the breakdown electric field of the defect, there is a spark bridging the defect, as show in figure 1. The sparks occurring in these defects induce transient currents whose bandwidth is in the range from 50 kHz to > 1.3 GHz dependent on composition of cable system. These transient currents flow along ground wire and sheath like travelling wave, and establish magnetic field, as show in figure 2. Therefore, the partial discharge signal can be sensed by means of inductive sensor such as high frequency current transducer or Rogowaski coil.



(a) b

Figure 1

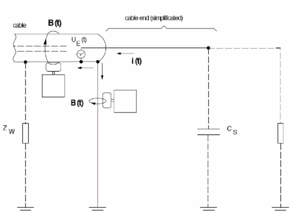


Figure 2

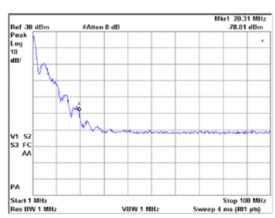


Figure 3

The bandwidth of conventional HFCT and Rogowaski coil is below 20 MHz. Unfortunate, the bandwidth of noise from power system is also in the range. Figure 3 is the noise spectrum of an industry plant measured by authors. Therefore, the interpretation of on-line partial discharge measurement becomes difficult due to the low signal-noise-ratio. On way to overcome this problem is to utilize a sensor with bandwidth of 30 MHz ~ 1.3 GHz(UHF sensor). The signal-noise-ratio is improved as the higher measuring frequency is used [6].

This paper puts a UHF sensor (LDIC UHF) above the spring clamp of cable terminations to measure their partial discharge signal, as shown in figure 4. The pattern is correlated to the outlet voltage therefore corona and interference problems could be disregard during measurement.

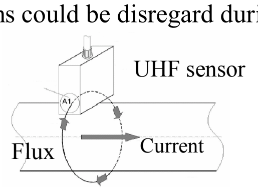


Figure 4

A performance test is taken place, and figure 5 shows the results. Figure 5 shows the sensitivity comparison between conventional PDM and on-line PDM, and on-line PDM can measure partial discharge signal only when partial discharge signal is larger than 20 pC. The phase-resolved patterns of both PDM, and it shows good agreement with each other.

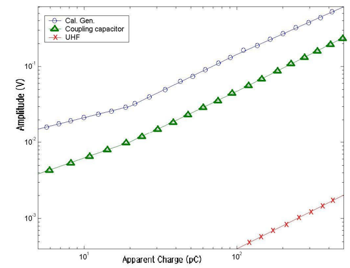


Figure 5 performance check

III. FIELD MEASUREMENT

Figure 6 shows a construction of cold shrink termination, and the red area is the most common location where partial discharge initiates. There are three cases of workmanship that can result in these phenomena. First, voids left in the cable termination due to the inadequate installation. Second, there are pollutants in cable termination resulted from casually clearance. Third, stress cone does not contact well to outer-semiconductor layer or the edge of outer-semiconductor is irregularity. Any one of above situations could result in partial overstress adjacent the defects, and the partial discharging happen. The characteristics of partial discharge in different type of defects are discussed as follows.

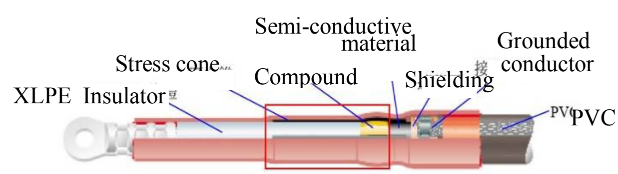


Figure 6

Table 2 Characteristic of defects in cable termination

	PD pattern	Appearance
Residual voids in cable termination	1.The area: 0º to 90º and 180º to 270º; 2.asymmetric partial discharge activities	Normal
Stress cone does not contact to out-semiconductor	1.The area: 0º to 90º and 180º to 270º; 2.symmetric partial discharge activities	Normal
Environment	Not always the same	Powder, protrusion Carbonization

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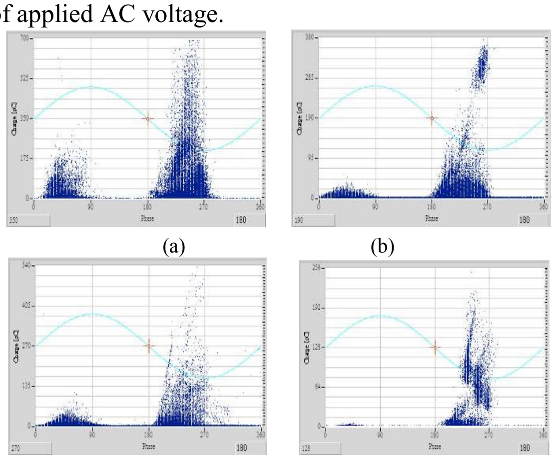
A. Residual voids in cable termination

Because the sheath is hard, cutting sheath usually complies with outer-semiconductor damaged. The insulation material is also easily damaged while cutting outer-semiconductor.

Aforementioned facts result in the irregular surface inside cable termination. Once workman does not smooth the irregular and fill the irregular with silicon grease, there will be a void leaved in cable termination. The inadequate heat shrink process also can cause void inside cable termination. There voids influent the distribution of electric field, and resulting inhomogeneous electric field. Hence, the partial overstress happens, and partial discharge activity exercises. Eventually, insulation material aging accelerates.

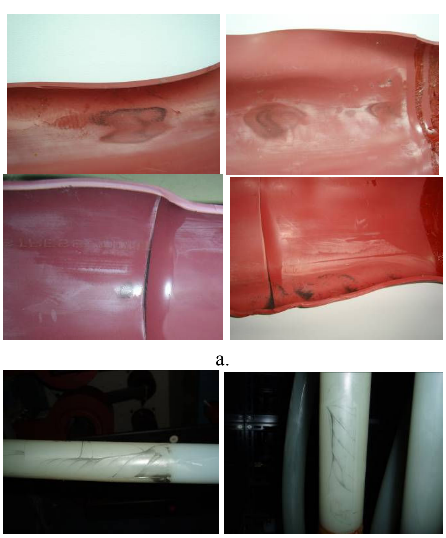
Figure 7 shows the partial discharge pattern measured in the field. The area of partial discharge is 0º to 90º and 180º to 270º, and the trace of partial discharge of negative half cycle are bigger than that of positive half cycle. The characteristics of these partial discharge patterns are alike to external partial discharge due to their peak partial discharge appears near the peak of applied AC voltage.



(a) (b) (c) (d)

Figure 7

These cable terminations having partial discharge activities is replaced, and the replaced cable terminations were dissected. There is carbonization inside the cable terminations, as shown in figure 8. Two reasons can explain this situation. One is void left in the cable termination due to the inadequate heat shrink (8a). Another is excessive carving (8b).



a.

b.

Figure 8

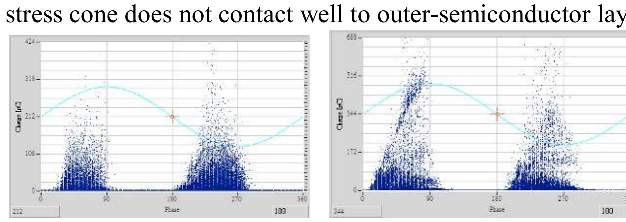
Once this kind of partial discharge activity starts, the carbonization will influent the distribution of electric field which will aggravate the aging adjacent the defects. Finally, a short circuit event occurs as shown in figure 9. The event of figure 9 is a kind of high impedance short circuit, and the initial fault current is low. Therefore, the insulation material is usually good without any discharge tracking, but there will be an obvious flashover tracking from defect to ground terminate. This is the property of the short circuit resulting from void discharge inside cable termination.

Figure 9

B. The stress control cone does not attach to out-semiconductor

The main function of cable termination is to control the electric field at the cable terminates not to overstress insulator. There is a great intensity of electric field at the end of out-semiconductor without the existence of cable termination, and then the insulation is aging quickly. Therefore, the cable termination loses its main function as the stress control, thyis means that the cone does not contact to outer-semiconductor very well. This kind of mistake is usually caused by wrong installation process without following installation manual, and is only occurred at cold shrink cable.

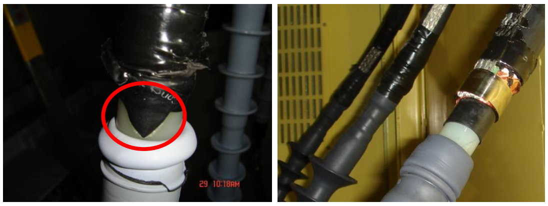
Figure 10 shows the partial discharge pattern measured in the field by means of on-line partial discharge measurement. The range of partial discharge is 0º to 90º and 180º to 270º, and the patterns of partial discharges of both half cycles are very close. After dissecting the cable terminations having the same patterns, the partial discharge pattern is classified as the stress cone does not contact well to outer-semiconductor layer.



(a) (b)

Figure 10

Figure 11 are dissected cable terminations having the same pattern shown in fig. 10. Figure 11a shows that not only poor contact between stress cone and semi-conductive layer of cable, but also the irregular tapping result in partial discharge phenomena. Figure 11b shows another case which the stress cone does not contact well to outer-semi conductive layer but the edge of tape is smooth. Both figure 11a and figure 11b will cause partial discharge, but the former is worse due to the greater intensity of electric field at the irregular shape.



a. b.

Figure 11

Figure 12 shows a fault event caused by such problem. The properties of this kind of faults are higher fault current and obvious tracking from conductor to grounded wire.

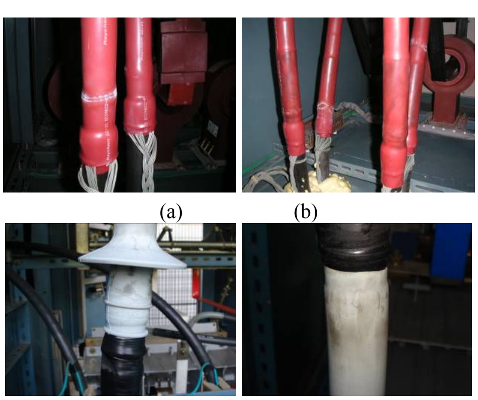
Figure 12

C. Environment factors: humidity and distance

Besides incorrect installation, there are other factors resulting in partial discharge. These environment-caused partial discharge phenomena could be easily detected by visual inspection. Figure 13 shows the partial discharge trace in the surface of cable terminations. These partial discharge phenomena usually resulted in un-uniform gradient of electric field relating to humidity and shape. The dangerous of these partial discharges is usually low degree. There is a potential danger that the trace bridging conductor and grounded wire will cause flashover along the surface, as shown in figure 14.

The amount of surface partial discharges depends on environment. As the humidity is high, the amount of surface partial discharge is large. Sometimes ultraviolet and sound comply with heavy partial discharge activities.

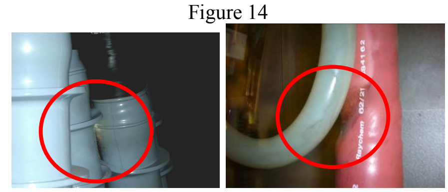
Another factor affecting external partial discharge is insufficient distance between cables, especially for the same phase cables. There is a different potential between cables due to un-uniform impedance along the cable. As the potential difference is higher than the breakdown voltage of air, partial discharge will occur, as shown in figure 15. If the discharge is disregarded, the fault event shown in figure 16 happens.



(a) (b) (c) (d)

Figure 13

Figure 14



(a) (b)

Figure 15

Figure 16

IV. Conclusion

As shown in figure 6 and figure 9, the partial discharge patterns of different defects may have similar patterns that the range of partial discharge is 0º to 90º and 180º to 270º, and the only different between them are the amount of partial discharge is balance at both half cycles of applied voltage for the second type of defects.

According to dissection of replaced cable terminations, the majority reason of cable fault is workmanship. Therefore, the education of workman is the essential consideration to lower down the rate of cable faults.

Base on the experience mentioned above, the application of UHF on on-line partial discharge measurement can be useful to prevent fault by detecting whether partial discharge exist or not. Unfortunately, the related testing method of on-line partial discharge measurement is not proposed yes. As so far, there is no rule to identify the type and location of defects by on-line partial discharge measurement, and the criterion still base on the experience of operators.

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